MR. ROSS WILLIAM FINLAY (Orcid ID : 0000-0002-0881-6448)

Article type : Management Brief

Title:

Development of a double-breakaway pass-through PIT-tag antenna system for flood-prone rivers

Suggested Running Head:

Double-breakaway PIT antenna system for flood-prone rivers

AUTHORS

Ross Finlay[a,b] | Russell Poole[b] | Thomas E. Reed[a]

[a] School of Biological, Earth and Environmental Sciences, University College Cork, Ireland

[b] Marine Institute, Furnace, Newport, Co. Mayo, Ireland

CORRESPONDENCE

Ross Finlay, Marine Institute, Furnace, Newport, Co. Mayo, Ireland.

Email: ross.finlay@marine.ie

Phone: 00353 852771075

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record. Please cite this article as doi: 10.1002/NAFM.10454

[A] Abstract

Pass-through passive integrated transponder (PIT) antennae are often used in river and stream habitats to monitor the movement of aquatic species. Where these habitats are prone to high flows containing suspended debris, traditional pass-through antennae designs are particularly vulnerable to damage which can be time consuming and expensive to repair and lead to extended gaps in data collection. We designed and tested a novel pass-through half duplex (HDX) antenna system that allows the antenna loop to (1) break away from one river bank under predetermined strain and (2) split into two separate cables, thereby shedding entangled debris that could otherwise damage or dislodge the antenna system. After break away events, our system can be rapidly reconnected and redeployed without the need for personnel to enter the water, reducing maintenance time and costs while minimizing gaps in data. In locations where pass-through antennae are prone to flood damage, this system offers distinct advantages over traditional designs.

[A] Introduction

Due to their small size, low cost and lack of internal batteries, PIT tags have proven to be a valuable tool for studying freshwater fish at various stages of their life histories (Bond et al., 2007; Castro-Santos et al., 1996; Conallin et al., 2012; Dodd et al., 2018; Furey et al., 2016; Haraldstad et al., 2016; Winter et al., 2016). Stationary in-stream antennae are commonly used to monitor the movement of PIT-tagged fish in dynamic fluvial environments where antennae are prone to damage from high flows and debris (Cooke et al., 2013). A number of flat-bed/pass-by antenna designs (i.e. where the antenna lies flat on the streambed) have been developed that are relatively robust to damage from flotsam (Armstrong et al., 1996; Greenberg and Giller, 2000; Johnston et al., 2009; Kazyak and Zydlewski, 2012; Lucas et al., 1999; Nunnallee et al., 1998). While flat-bed antennae are effective at detecting tags passing close to the streambed, their horizontal orientation limits their vertical read range. Pass-through antennae, by virtue of their vertical orientation, are able to detect tags that are significantly higher in the water column. Additionally, because PIT tags generally lie horizontally when implanted in fish, they are ideally oriented for detection by pass-through antennae. These attributes make pass-through antennae particularly well suited to sites with relatively deep water or to studies where the morphology of the target species necessitates the use of small (i.e. 12 mm) PIT tags that produce weak signals. However, the vertical orientation of pass-through antennae can expose them to greater stresses than flat-bed designs, particularly in cases where flotsam becomes caught on the antenna loop.

In order to investigate the migratory phenology and survival of Atlantic salmon *Salmo salar* L. and brown trout *Salmo trutta* L. smolts, we constructed and installed a series of five HDX PIT antennae (ranging in width from 2.5 m to 18 m) in the Burrishoole river system in the West of Ireland (Figure 1). HDX systems were chosen over FDX systems due to their ability to power wide, flexible antennae that are simple to construct and present a reduced profile in the water column. Due to water depth at our installation sites, the tendency of smolts to travel close to the water surface (Moore et al., 1998; Scruton et al., 2005; Thorstad et al., 2012) and our fish size-necessitated use of 12 mm tags, pass-through antennae were deemed preferable to flat-beds. However, the Burrishoole river system is prone to frequent high flow events that often carry large debris from forestry located upstream (O'Toole et al., 2015 and Figure 2). Initial installations for this project that were based on traditional pass-through designs proved susceptible to catastrophic damage during floods, particularly when large flotsam became entangled in the loop of the antenna cable. Such occurrences necessitated the construction and installation of replacement antenna systems, leading to extended gaps in data collection and representing significant costs in materials and labour. In response, we designed a new pass-through antenna system with the requirements that (a) high flow events or floating debris would not cause significant damage, and (b) any post-flood maintenance or redeployment of the system should be simple, rapid and cheap.

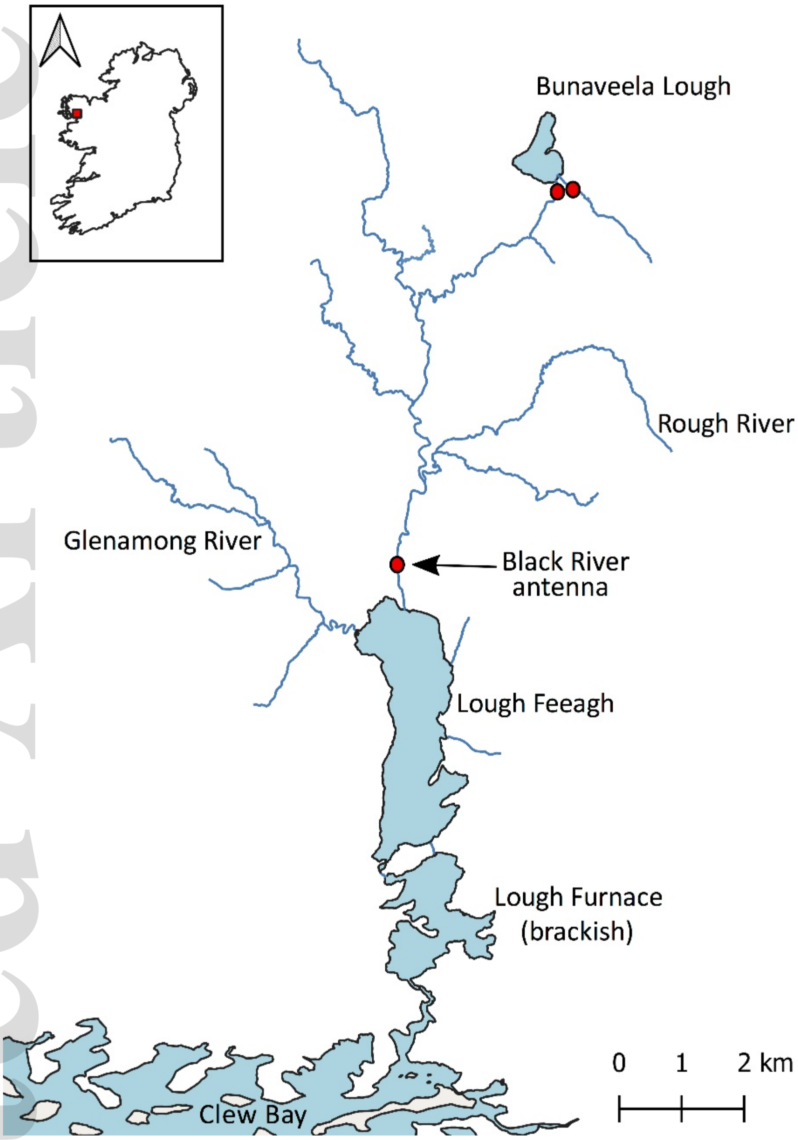

FIGURE 1. —Map of the Burrishoole catchment with antenna locations marked as red circles. Each of the two northerly locations represent antenna arrays comprised of two antennae.

FIGURE 2. — Black river antenna location at normal river height (A) and during a flood (B). The top of the antenna is visible just above the water surface in image (A).

[A] Materials and Methods

Here we describe an antenna system installed in March 2018 at our most challenging site (stream width and height 1800 cm and ~ 65 cm respectively under normal flow conditions). To span this section of river, we constructed a 1750 cm X 75 cm rectangular antenna from a single turn of 6 mm^2 (~ 9 American wire gauge (AWG) equivalent) multi-strand PVC sheathed coper wire (Figure 3, part 1). Antenna inductance, as measured with an Extrech Instruments LCR meter, was 41.3 µH. The antenna cable was passed through a 12 mm internal diameter braided PVC hose pipe (Figure 3 and 4, part. 2) to provide protection from abrasion. A 20 cm section of hose located at the intended midpoint of the antenna loop was slit lengthways, cut crosswise at each end, and removed (Figure 3, 4 and 5, part 3). The antenna cable was severed at the midpoint of the gap created and male and female pin components from a seven pin trailer board plug were soldered to the severed ends of the cable, allowing these ends to be reconnected (Figure 5 a).

Once connected, the plug assembly was sealed with electrical tape to provide waterproofing and a minor degree of tensile support. The previously removed section of hose (part 3) was replaced in its original position and secured to the cut ends of the hose with cable ties and stoppers made from electrical tape (Figure 4 and 5 b), allowing this section of hose and the cable within to separate or break away under relatively low strain. The sections of hose covering the two horizontal (top and bottom) sections of the antenna were cable-tied to two sections of 10 mm pre-stretched dyneema support ropes (Figure 3 and 4, part 4) with a rated breaking strain of 5000kg. A MIN-E-MAX™ (DCD Design and Manufacturing Ltd., British Columbia) breakaway connector (Part No. 00530-010) loaded with a 600 lb (272 kg) breakaway pin (Part No. 00555-006) (Figure 3 and 4, part 5) was attached to each support rope at the end nearest the plug assembly, allowing the rope to break away at this location as strain on it approached 300 kg.

Stainless steel carabiners (1500 kg breaking strain) were used to secure the breakaway connectors to two M10 eye bolts (Figure 4, part 6) that were driven through pre-drilled holes located 7 cm and 82 cm from the bottom of a 10 cm wide, 200 cm long pressure treated round timber post (Figure 3 and 4, part 7). Each eye bolt was secured with washers and two lock nuts. A second 10 cm wide round timber post (Figure 3 and 6, part 8) measuring 270 cm was furnished with eye bolts in the same manner as the first post and single (Fig 3 and 6, part 9) and double (Figure 3 part 10) blocks (pulleys) with a 1500 kg rating were secured to the bottom and top eye bolt respectively. The free end of the lower support rope was passed through the bottom block before it and the upper rope were passed through the top block and secured to a hand winch (Figure 3, part 11) mounted to the top of the support pole (part 8) with M10 bolts, lock nuts and a bracing plate. Two mounting tubes (Figure 3 and 6, part 12) were constructed by cutting two 8 mm wide strips from opposite sides of two 180 cm long, 15 mm-walled HDPE pipes with 10.5 cm internal diameters, leaving 7 cm of uncut material at one end (the bottom) of each tube.

The antenna support poles were inserted into the mounting tubes (Figure 6) until the protruding lower eye bolts reached the uncut end. Two 30 mm wide ratchet straps (Figure 4 and 6, part 13) were used to connect three Duckbill Earth Anchors ® (MacLean Civil Products, South Carolina)

(Figure 3 and 6, part 14) to the rear uncut bottom section of each tube. Two ratchet straps were also used to connect three Duckbill Earth Anchors to the rear of each tube just above the top eye bolt while pressure from these straps also clamped the tubes securely onto the support poles. Extended drive rods were used to secure the lower Duckbill anchors to the streambed at each bank before the upper anchors were secured horizontally into the bank itself. The hand winch was then used to simultaneously tension the top and bottom support ropes after which the handle was removed to discourage tampering.

Once the system was installed as described above, an ATC Auto Tuner (Oregon RFID, Oregon) (Figure 3, part 15) was mounted to a vertical post located beside support pole (part 8), and connected to the free ends of the antenna cable in order to adjust antenna capacitance. A Multi-Antenna HDX Reader (Oregon RFID, Oregon) was connected to the auto tuner by shielded Belden 9207 twinaxial cable which transmits power and data. Due to danger from flooding (Figure 2), the reader was located in a sealed box on high ground 60 m from the antenna installation site and the twinaxial cable was buried to ~ 10 cm. Power for the system was provided by a bank of five 120 Ah AGM 12V batteries connected in parallel which were swapped out periodically.

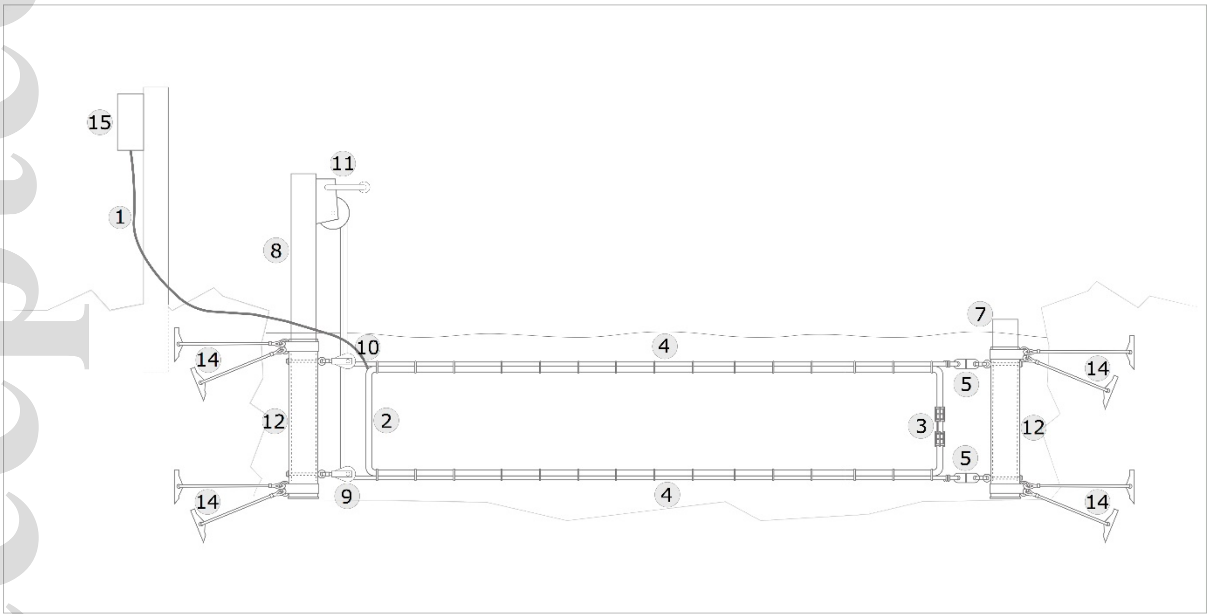

FIGURE 3. —Diagram of the double breakaway antenna system (not to scale). Numbered circles designate parts described in the Antenna Construction section.

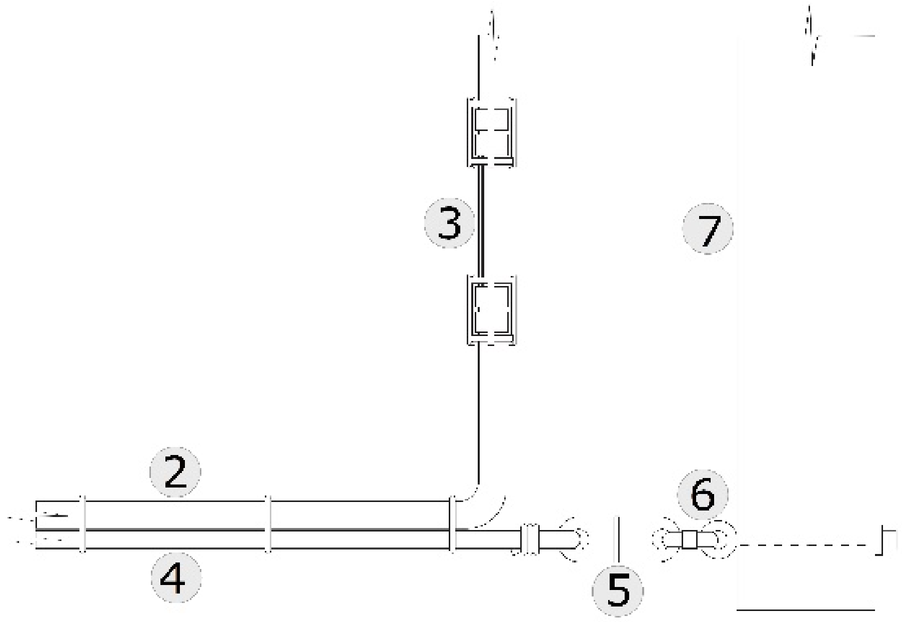

FIGURE 4. —Diagram showing the lower breakaway connector assembly and the breakaway section of the antenna cable (not to scale). Numbered circles designate parts described in the Antenna Construction section.

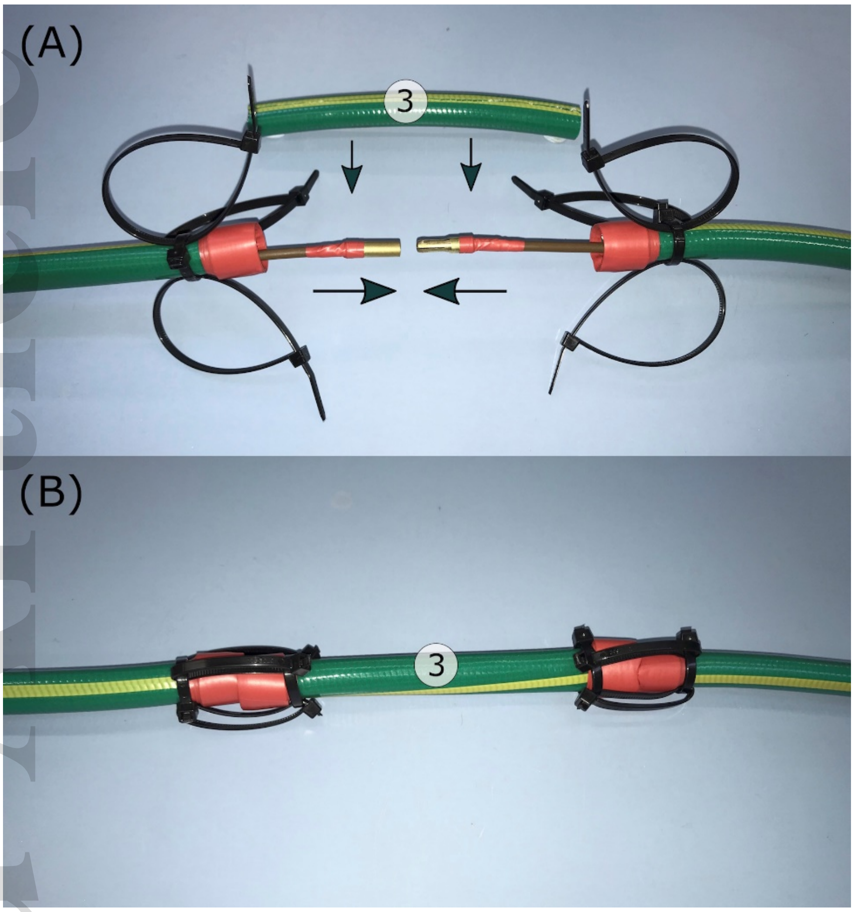

FIGURE 5. — Photograph of the breakaway plug assembly (A) separated and (B) assembled and ready for deployment.

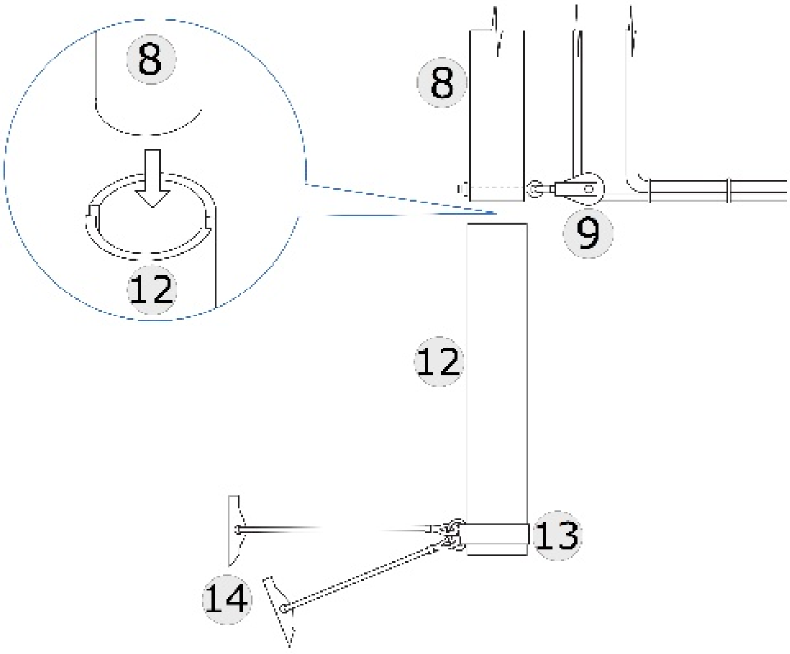

FIGURE 6. —Diagram showing the lower (single) pulley assembly and the method of inserting the support poles into the mounting tubes (not to scale). Numbered circles designate parts described in the Antenna Construction section.

[A] Results

[B] Tag Detection

We tested the in-stream performance of our antenna with 12 mm 134.2 kHz HDX tags manufactured by Oregon RFID and Biomark Inc., Idaho. When orientated perpendicular to the antenna, both companies' tags were detected at all points within the loop and up to 10 cm outside it, providing ~ 95 cm of vertical detection coverage and ~ 1770 cm of horizontal coverage. Tags were detected from roughly 20 cm upstream to 20 cm downstream of the antenna, providing a 'reading frame' (*sensu* Bond et al., 2007) of about 40 cm.

[B] Breakaway Operation and Maintenance

Between March 2018 and September 2019, regular high flow events occurred in the Burrishoole catchment (Figure 7). On seven of these occasions the strain on the antenna system exceeded the predetermined pin limit (272 kg), causing the MIN-E-MAX™ breakaway connectors to separate. On each occasion the trailer plug pin connection also separated, allowing flotsam to pass without becoming tangled in the antenna cable. Consequently, no significant damage to the antenna system occurred within the operating period. After breakaway events, the loose ends of the antenna were laid on the western river bank (nearest the autotuner) and the trailer plug assembly was reconnected and sealed as described above. The upper ratchet straps were briefly removed from mounting tube on the opposite bank, allowing the support pole (part 7) to be removed and brought to the western river bank where the upper and lower MIN-E-MAX™ breakaways could be reconnected and loaded with new pins.

The winch was then used to slacken the support ropes, allowing the support pole (part 7) to be dragged across the river with a rope and reinstalled in its mounting tube as described above. In situations where the far bank can only be accessed by wading, it may be simpler to simply carry the support pole across. Finally, the support ropes were re-tensioned with the winch, allowing the antenna to recommence operation. The complete post-breakaway reinstallation process can be accomplished by two operators in less than 45 minutes and, in cases where both banks are accessible without wading, does not require either operator to enter the river. Additionally, if required, the two support poles (part 7 and 8) can be removed from their mounting tubes (part 12) in minutes, allowing the entire antenna to be removed from the installation site and easily reinstalled at a later date. In order to protect the mounting tubes in the interim it is recommended to insert a 10 cm wide round timber post into each (roughly equal in length to the tube) and tighten the upper ratchet straps (part. 13).

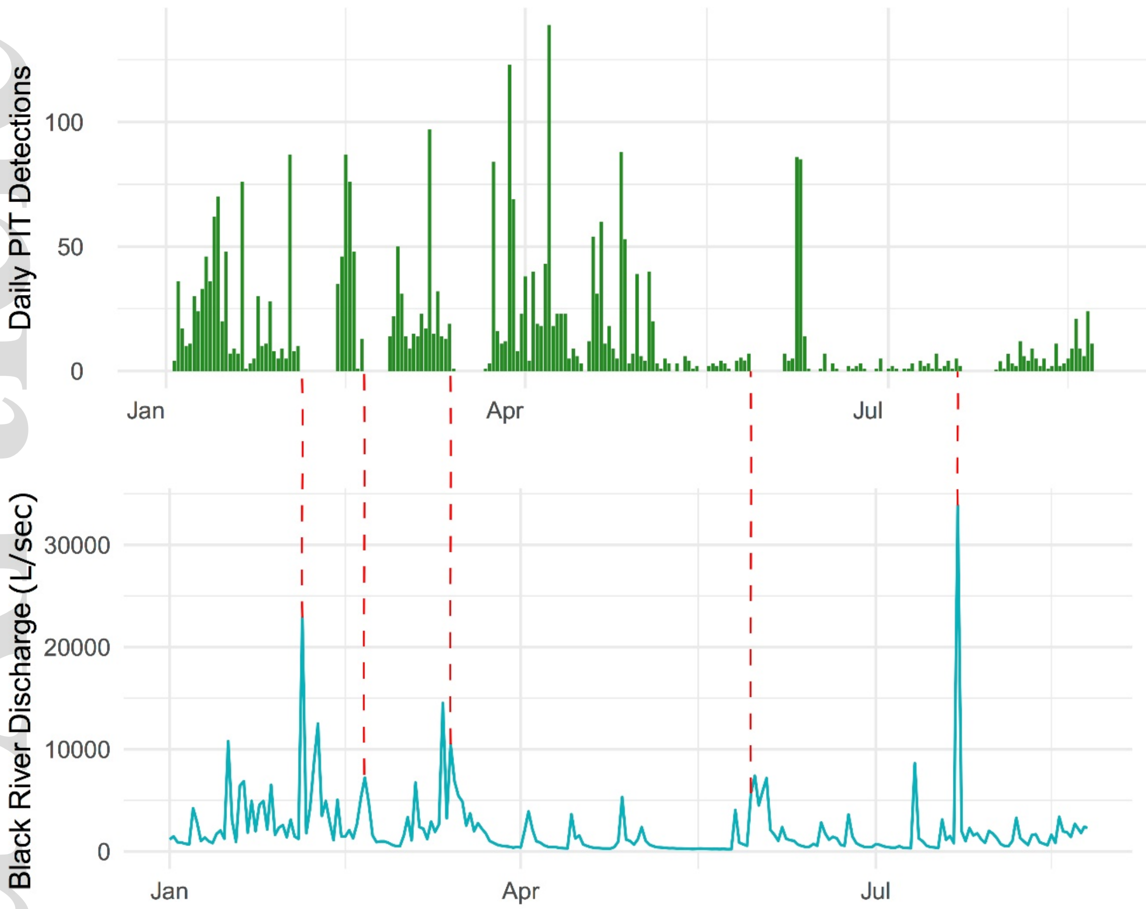

FIGURE 7. —Number of PIT tag detections recorded on the Black River antenna and average daily discharge (L/sec) from the Black River, January 2019 to August 2019. Antenna breakaway events are indicated by dashed vertical lines.

[A] Discussion

At its most basic, a PIT antenna is an unbroken loop of conductive cable. Pass-through, as opposed to flat-bed, PIT antennae are often used in river and stream habitats to monitor the movement of aquatic species (Bond et al., 2007; Haraldstad et al., 2016; Kazyak and Zydlewski, 2012; Winter et al., 2016; Zydlewski et al., 2001). When installed in a river in pass-through orientation, PIT antennae can be exposed to significant strain that increases dramatically as antenna size or water velocity increases or when debris become entangled in the cable loop. Against this background, our double-breakaway system exhibits three major advantages over traditional pass-through designs. Firstly, by breaking away from one bank and then opening the antenna loop, our system can withstand high flow events and the passage of suspended debris without sustaining significant damage. Secondly, after breakaway events occur, the system can be rapidly redeployed by two operators. Furthermore, if both banks of the river or stream are accessible, redeployment can be carried out without the need for personnel to enter the river. Finally, the use of mounting tubes allows the entire antenna to be rapidly removed and reinstalled at a later date, a beneficial feature for monitoring programmes focused on seasonal phenomena (i.e. salmonid smolt or spawning migrations).

The system described here represents a design framework that can and should be modified to suit local conditions. Construction, assembly and installation of the system is relatively simple but does require rudimentary DIY experience as well as a practical understanding of PIT technology. Due to our requirement for ~ 18 m (stream width) of horizontal PIT tag detection coverage at our installation site, a single loop antenna was found to outperform multi-loop designs. Where stream-width is narrower (i.e. < 10 m), multi-loop antennae are often required to achieve appropriate inductance (Arnaud et al., 2015; EE-Web, 2020; Miller, 2011; Steinke and Anderson, 2011). These can be accommodated by the system described here with the minor modification that each additional turn of cable will require an additional plug assembly. We conservatively used 600 lbs (272 kg) breakaway pins in our system due to the soft river substrate (peat silt) and bank composition at our installation site which reduced the tensile grip of the Duckbill anchors. Where anchors can be mounted more securely, stronger breakaway pins may reduce the frequency of breakaway events and increase continuity of data collection. It is crucial to ensure that all load-bearing components used in the antenna system are significantly stronger than the chosen breakaway pins. River substrate in some areas may prove to be unsuitable for securing Duckbill anchors, particularly in locations where the riverbed is dominated by large rocks. Other mounting equipment may provide a solution in such cases although it may often be preferable to find an alternate location. Additionally, this system can be most easily and securely installed in locations where a river and its banks form a relatively square cross section. Both of these considerations should be taken into account when assessing potential installation sites. As with any PIT antenna installation in fluvial habitats, it is also vital that antenna amperage is maintained within safe limits at all times.

Although pass-through antennae are generally exposed to greater strain than similar-sized flat-beds, their increased vertical read range and detection performance represent distinct advantages as water depth increases. Our double-breakaway system can facilitate the long-term operation of pass-through antennae in locations where high flows and floating debris make traditional pass-through designs unfeasible.

[A] Acknowledgements

This work was funded by the Marine Institute Cullen Fellowship award CF/15/06. TER was funded by an ERC Starting Grant (ERC- 2014-StG-639192-ALH) and an SFI ERC Support Award. We thank the staff of the Marine Institute Burrishoole research facility, Newport, the field staff of the FishEye research group, Peter Deegan, and the staff of University College Cork for their logistical support throughout the project.

[A] References

Armstrong, J.D., Braithwaite, V.A. and Rycroft, P. (1996), "A flat-bed passive integrated transponder antenna array for monitoring behaviour of Atlantic salmon parr and other fish", *Journal of Fish Biology*, Vol. 48, pp. 539–541.

Arnaud, F., Piégay, H., Vaudor, L., Bultingaire, L. and Fantino, G. (2015), "Technical specifications of low-frequency radio identification bedload tracking from field experiments: Differences in antennas, tags and operators", *Geomorphology*, Elsevier B.V., Vol. 238, pp. 37–46.

Bond, M.H., Hanson, C. V, Baertsch, R., Hayes, S.A. and MacFarlane, R.B. (2007), "A new low-cost instream antenna system for tracking passive integrated transponder (PIT) -tagged fish in small streams”, *Transactions of the American Fisheries Society*, Vol. 136, pp. 562–566.

Castro-Santos, T., Haro, A. and Walk, S. (1996), “A passive integrated transponder (PIT) tag system for monitoring fishways”, *Fisheries Research*, Vol. 28 No. 3, pp. 253–261.

Conallin, J., Jyde, M., Filrup, K. and Pedersen, S. (2012), “Diel foraging and shelter use of large juvenile brown trout (Salmo trutta) under food satiation”, *Knowledge and Management of Aquatic Ecosystems*, Vol. 404 No. 5, pp. 1–6.

Cooke, S.J., Midwood, J.D., Thiem, J.D., Klimley, P., Lucas, M.C., Thorstad, E.B., Eiler, J., et al. (2013), “Tracking animals in freshwater with electronic tags: past, present and future”, *Animal Biotelemetry*, Vol. 1 No. 5, pp. 1–19.

Dodd, J.R., Cowx, I.G. and Bolland, J.D. (2018), “Win, win, win: Low cost baffle fish pass provides improved passage efficiency, reduced passage time and broadened passage flows over a low-head weir”, *Ecological Engineering*, Vol. 120, pp. 68–75.

EE-Web. (2020), “Coil Inductance Calculator”, *EE-Web*, available at: https://www.eeweb.com/tools/coil-inductance (accessed 19 April 2020).

Furey, N.B., Hinch, S.G., Bass, A.L., Middleton, C.T., Minke-Martin, V. and Lotto, A.G. (2016), “Predator swamping reduces predation risk during nocturnal migration of juvenile salmon in a high-mortality landscape”, *Journal of Animal Ecology*, Vol. 85, pp. 948–959.

Greenberg, L.A. and Giller, P.S. (2000), “The potential of flat-bed passive integrated transponder antennae for studying habitat use by stream fishes”, *Ecology of Freshwater Fish*, Vol. 9, pp. 74–80.

Haraldstad, T., Kroglund, F., Kristensen, T., Jonsson, B. and Haugen, T.O. (2016), “Diel migration pattern of Atlantic salmon (Salmo salar) and sea trout (Salmo trutta) smolts: an assessment of environmental cues”, *Ecology of Freshwater Fish*, Vol. 26 No. 4, pp. 541–551.

Johnston, P., Berube, F. and Bergeron, N.E. (2009), “Development of a flatbed passive integrated transponder antenna grid for continuous monitoring of fishes in natural streams”, *Journal of Fish Biology*, Vol. 74, pp. 1651–1661.

Kazyak, D. and Zydlewski, J. (2012), “High-Density Polyethylene Pipe: A New Material for Pass-By Passive Integrated Transponder Antennas”, *North American Journal of Fisheries*

Management, Vol. 32 No. January 2015, pp. 49–52.

Lucas, M.C., Mercer, T., Armstrong, J.D., McGinty, S. and Rycroft, P. (1999), "Use of a Flat-bed passive integrated transponder antenna array to study the migration and behaviour of lowland river fishes at a fish pass", *Fisheries Research*, Vol. 44, pp. 183–191.

Miller, E.K. (2011), "Time-Domain Computation of Loop inductance", *IEEE*, No. 6, pp. 62–65.

Moore, A., Ives, S., Mead, T.A. and Talks, L. (1998), "The migratory behaviour of wild Atlantic salmon (Salmo salar L.) smolts in the River test and Southampton Water, southern England", *Hydrobiologia*, Vol. 371, pp. 295–304.

Nunnallee, E.P., Prentice, E.F., Jonasson, B.F. and Patten, W. (1998), "Evaluation of a flat-plate PIT tag interrogation system at Bonneville Dam", *Aquacultural Engineering*, Vol. 17, pp. 261–272.

O'Toole, C.L., Reed, T.E., Bailie, D., Bradley, C., Cotter, D., Coughlan, J., Cross, T., et al. (2015), "The signature of fine scale local adaptation in Atlantic salmon revealed from common garden experiments in nature", *Evolutionary Applications*, Vol. 8 No. 9, pp. 881–900.

Scruton, D.A., Pennell, C.J., Robertson, M.J., Clarke, K.D., Eddy, W. and McKinley, R.S. (2005), "Telemetry studies of the passage route and entrainment of downstream migrating wild Atlantic salmon (Salmo salar) smolts at two hydroelectric installations on the Exploits River, Newfoundland, Canada", in Spedicato, M.T., Lembo, G. and Marmulla, G. (Eds.), *Aquatic Telemetry: Advances and Applications. Proceedings of the Fifth Conference on Fish Telemetry*, Ustica, pp. 91–101.

Steinke, K. and Anderson, J. (2011), *Aquatic PIT Tag Interrogation System Construction and Standard Operating Procedure*, Abernathy.

Thorstad, E.B., Whoriskey, F., Uglem, I., Moore, A., Rikardsen, A.H. and Finstad, B. (2012), "A critical life stage of the Atlantic salmon Salmo salar: Behaviour and survival during the smolt and initial post-smolt migration", *Journal of Fish Biology*, Vol. 81 No. 2, pp. 500–542.

Winter, E.R., Tummers, J.S., Aarestrup, K., Baktoft, H. and Lucas, M.C. (2016), "Investigating the phenology of seaward migration of juvenile brown trout (Salmo trutta) in two European populations", *Hydrobiologia*, Vol. 775 No. 1, pp. 139–151.

Zydlewski, G.B., Haro, A., Whalen, K.G. and McCormick, S.D. (2001), "Performance of stationary and portable passive transponder detection systems for monitoring of fish movements", *Journal of Fish Biology*, Vol. 58 No. 5, pp. 1471–1475.